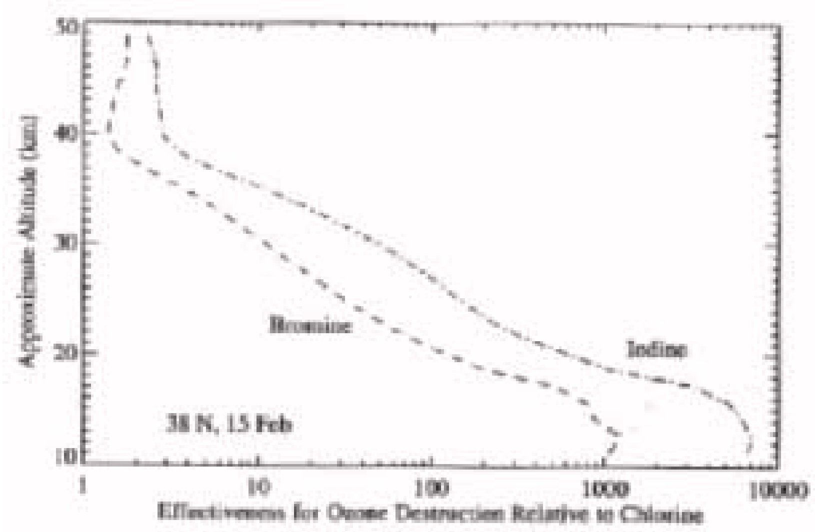
The Challenge – The Approach

- Production of halons used for fire protection was phased out in 1994 under the Montreal Protocol on Substances that Deplete the Ozone Layer
- Responsible stewardship has been demonstrated by the fire protection community
- Scientific exploration for halon replacements is one aspect of reducing stratospheric ozone depletion
- Engineering design of implementable cost effective systems is equally critical

Halons and the Stratospheric Ozone Layer

- 1974 Mario Molina and Sherwood Roland: CFCs accumulating in atmosphere will cause ozone depletion
- 1976 NRL Homer Carhart and Denis Bogan: Halons at least as efficient as CFCs in causing depletion (kinetics estimate)
- Detailed modeling: Magnified depletion effect of halon



NRL Halon Replacement Efforts

- Efforts began in early 1970s, prior to stratospheric ozone environmental concerns
- Improve fire protection for a variety of scenarios
- Scientific understanding of suppression

NRL 1970s Studies

- Smoldering combustion
- Halon kinetics
- Cup burner exploration
- Chemical and physical effects quantified
- HF, HBr quantified from total flooding Halon 1301 extinguishment
- Full scale Halon 1301 evaluation / shipboard system guidance

Full Scale Total Flooding Evaluation

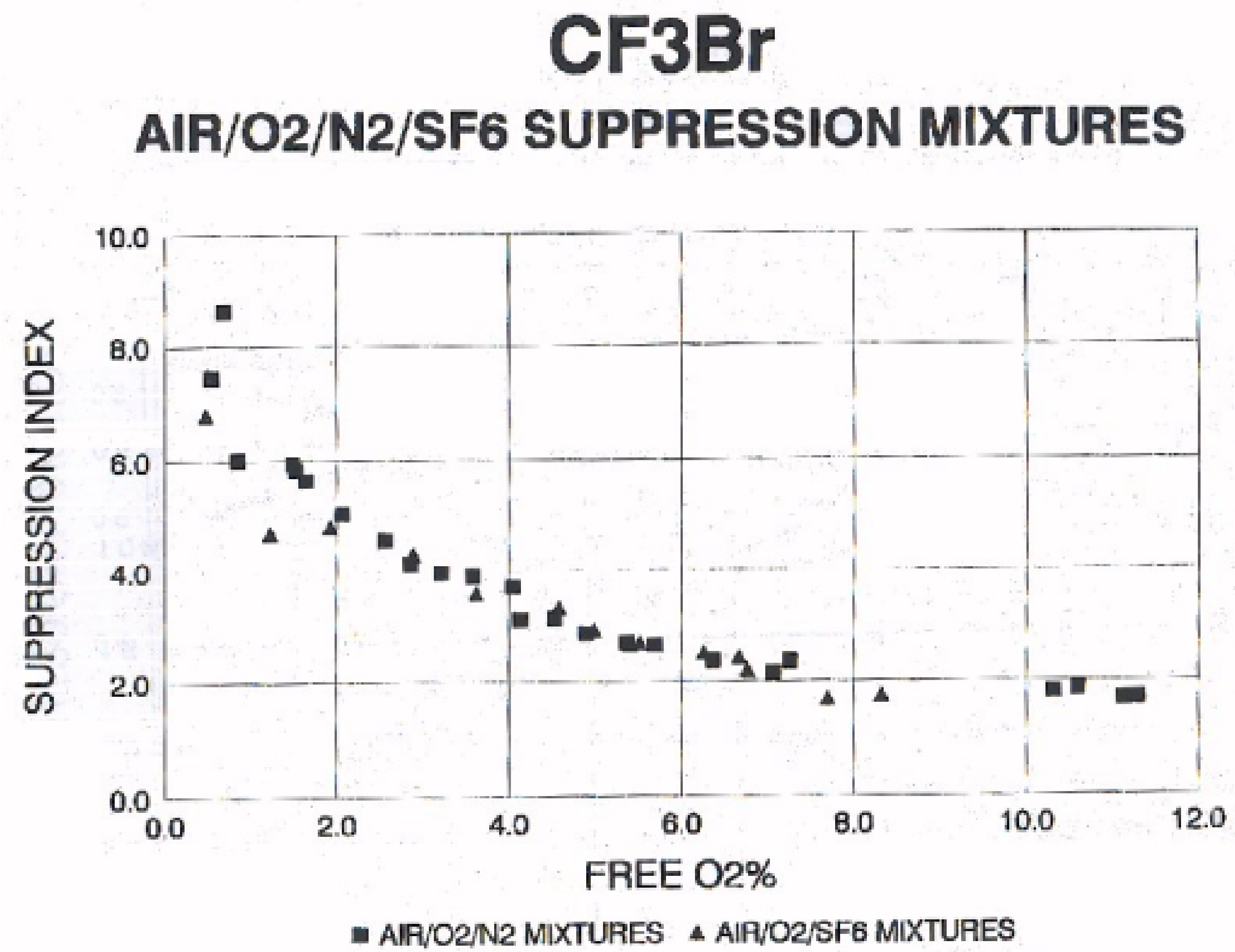
Fire 1 - 324 m^3 confined space/submarine fire test facility

- Inert gas (N_2)
- Fine water mist

Suppression Effectiveness Modeling

- Calculate effectiveness
  - CF_3Br 20% physical
  - CF_3 25% chemical scavenging
  - Br 55% chemical catalytic
- Predict suppressant mixture effectiveness, including for non-linear effects.
- Extend predictions for oxygen depleted or enriched environments

O_2 Conc.	N_2 Conc.	SF_6 Conc.	Free Oxygen	1301 Required
19.7%	80.8%	0%	5.37%	2.00%
26.9%	50.8%	21.2%	5.40%	2.03%

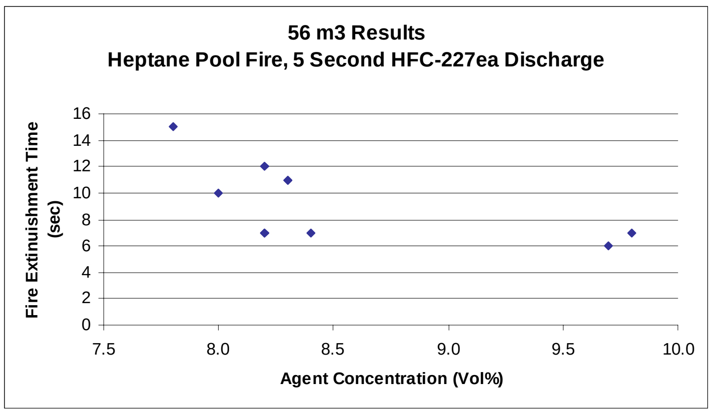

CF3Br
AIR/O2/N2/SF6 SUPPRESSION MIXTURES
SUPPRESSION INDEX
10.0
8.0
6.0
4.0
2.0
0.0
0.0
2.0
4.0
6.0
8.0
10.0
12.0
FREE O2%
AIR/O2/N2 MIXTURES
AIR/O2/SF6 MIXTURES

Intermediate Scale – 56 m^3 Initial Evaluation

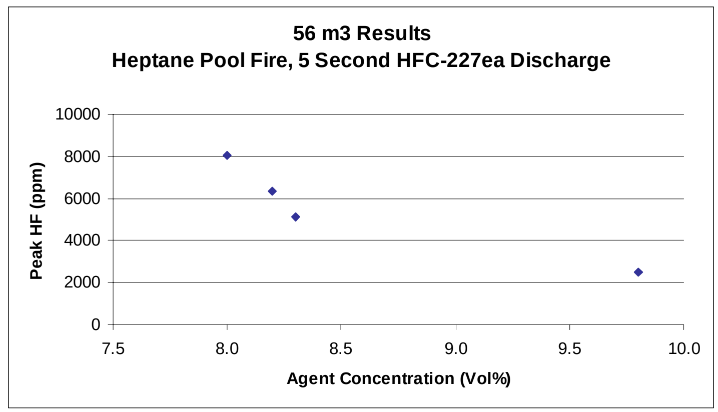
- Ten candidate and model suppressants
- Varied
  - Size of n-heptane pool and spray fires
  - Agent concentration and discharge time
- Determined fire out time and O_2, CO_2, CO, Agent, HF, and HBr concentrations
- Selected HFC-23, HFC-227ea and PFC-410 for further evaluation

Agent Design Concentration

- Cup burner gives the extinction concentration
- There is not a corresponding single concentration value for real applications
- Should consider protection requirement, toxic product formation, system space, weight, and cost



Extinguishment time vs. agent concentration

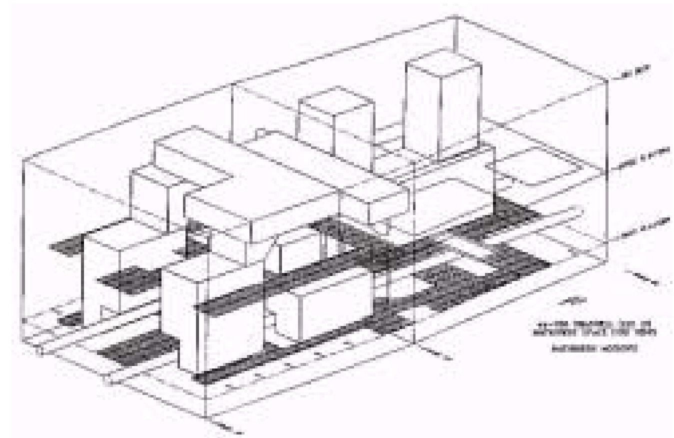


HF concentration vs. agent concentration

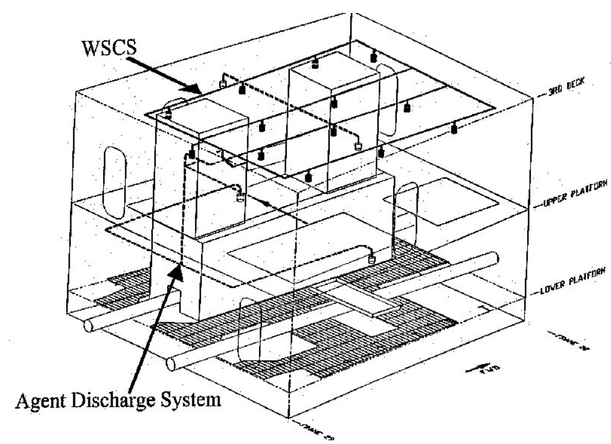
Ex-USS Shadwell

NRL's Advanced Fire Research Vessel

Ex-USS Shadwell (139 m)



Machinery Space Test Compartment (840 m^3)



Agent and WSCS Pipe Layout (395 m^3)

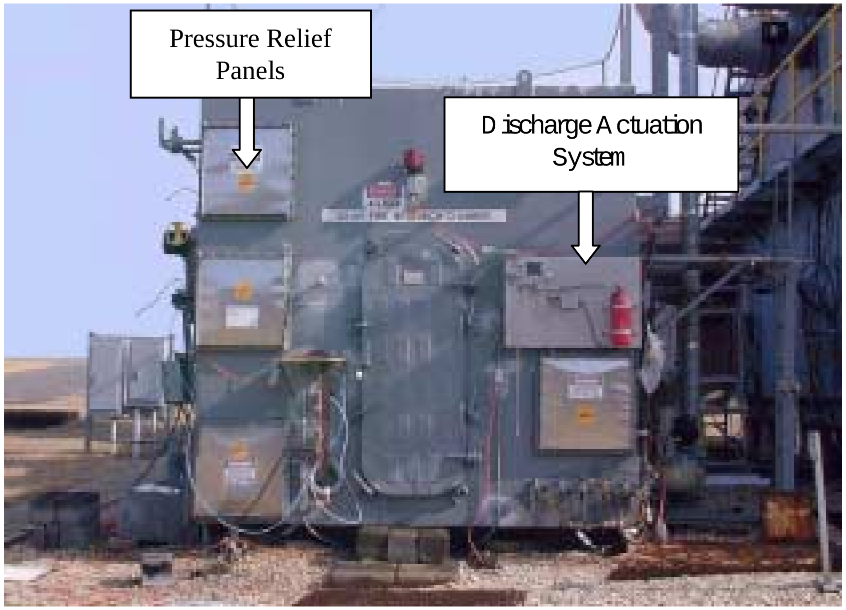
Different Design Concentration Guidance for Different Threats

- HFC-227ea selected as clean agent for Navy engine room fire protection
- Navy engine room
  - Large obstructions with open areas, hydrocarbon fuels (cup burner = 6.5% HFC-227ea for heptane)
- Guidance 8.5% x 1.2 (inhomogeneities) = 10.2%
  - safety factor not included
- Flammable liquid store room (FLSR)
  - Very obstructed, alcohols including highly volatile methanol (cup burner = 8.9% HFC-227ea)
  - Expect to require > 12%
- More challenging threat. Need to perform tests.

NRL Field Test Facility

Compartment 1 – 28 m^3 Fire Research Chamber

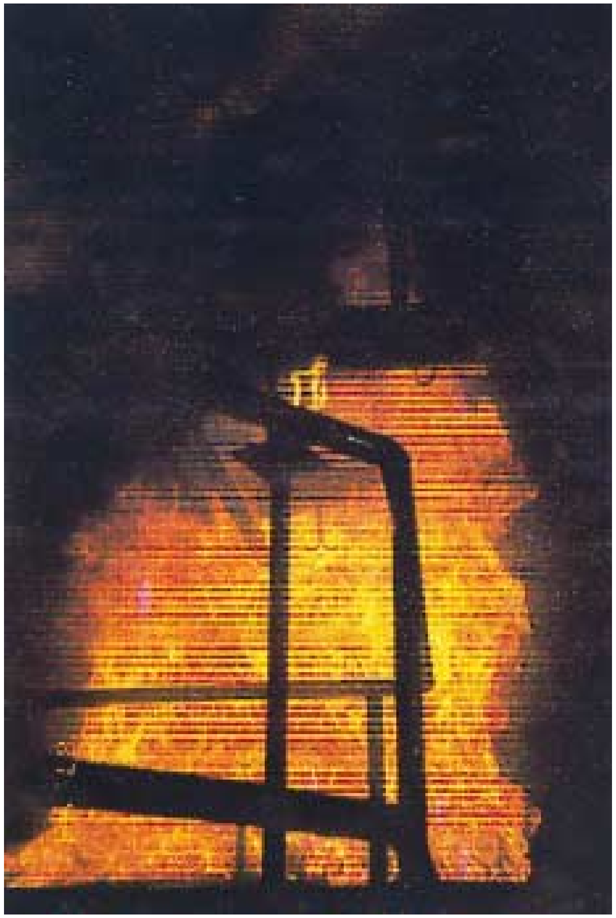
- FLSR fire threat: cascading - 80% methanol - 20% heptane mixture
- Realistic Navy configuration and hardware
- Pressure relief panels in case of energetic deflagrations



Flammable Liquid Fires

Flammable Liquid Store Room (FLSR)

28 m^3 Halon Replacement Test Bed



Ex-USS Shadwell: NRL Fire Research and Test Ship

840 m^3 Halon Replacement Machinery Space Test Bed

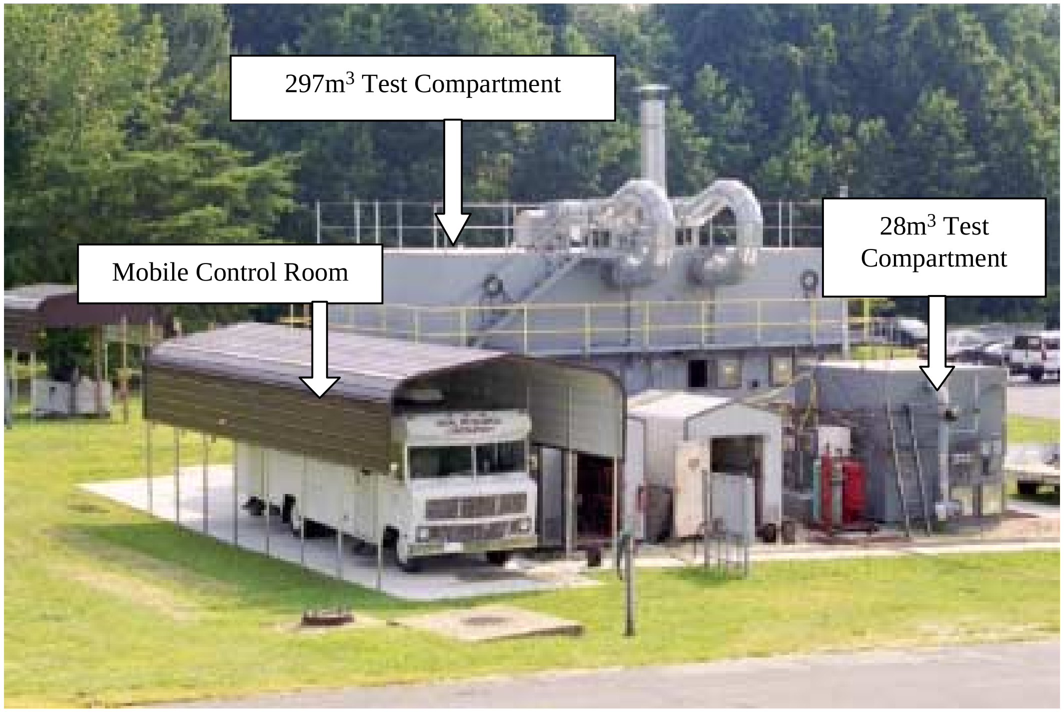
Halon Replacement Full Scale Test Compartments

Number 1: representative small compartment

Number 2: maximum size for 2 nozzle system

Number 3: representative large compartment

Volume (m3)	Length (m)	Width (m)	Height (m)
#1 28.0	3.05	3.05	3.05
#2 126	10.7	3.86	3.05
#3 297	10.7	6.10	4.57



Computer test control and data acquisition from Mobile Control Room

HFC-227ea Suppression Test Results, Compartments 1 and 2

- Extinguishment time and HF concentrations increased for 126 m^3 compartment despite higher agent concentration
- Further testing required to establish valid design guidance for larger compartments

	28 m^3	**126 m^3**
Design Concentration (Vol %)	11.1	11.6
Cascading Fire Extinguishment (sec)	8	13
Pan Fire Extinguishment (sec)	10	8
Peak HF (ppm)	2500	4000
Average HF after 15 minutes (ppm)	40	300

Compartment 3 Fire Scenarios

- 400 kW Fire for Fire Suppression Challenge
  - Evaluated and ruled out 830 kW fire, too much O_2 depletion
  - 400 kW chosen as the fire size
- 1900 kW Fire for Re-entry Challenge
  - Large fire easier to extinguish, but generates more heat and toxic HF
- One minute preburn before agent discharge
- Reignition attempted for both fires as part of tests

Pan Fire

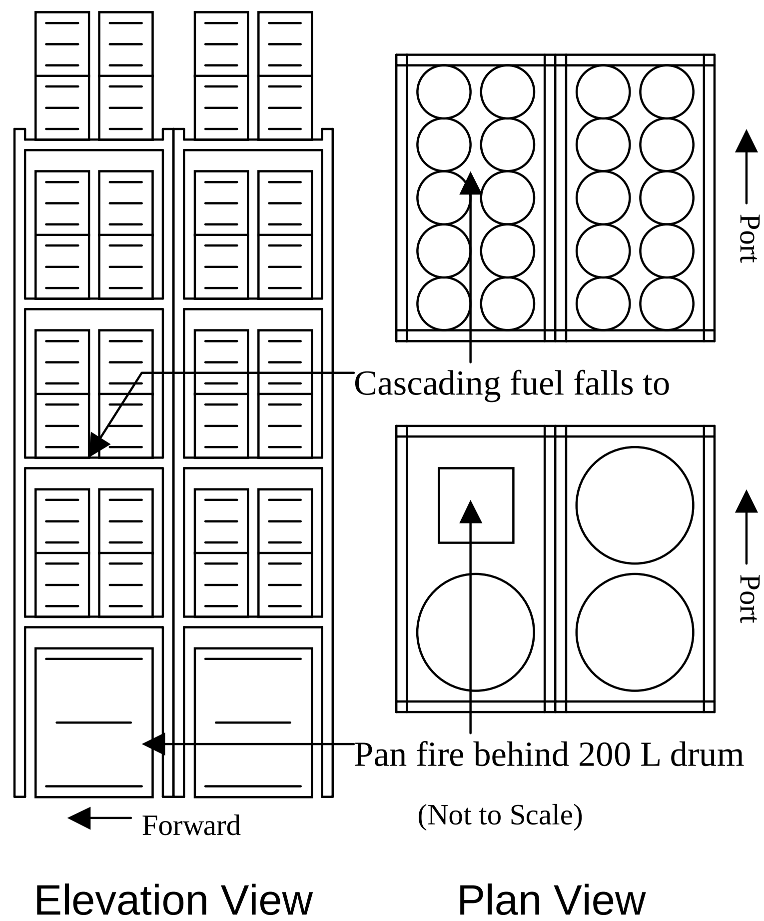
- Two-dimensional
- 30 cm above deck
- 70 kW

Cascading Fire

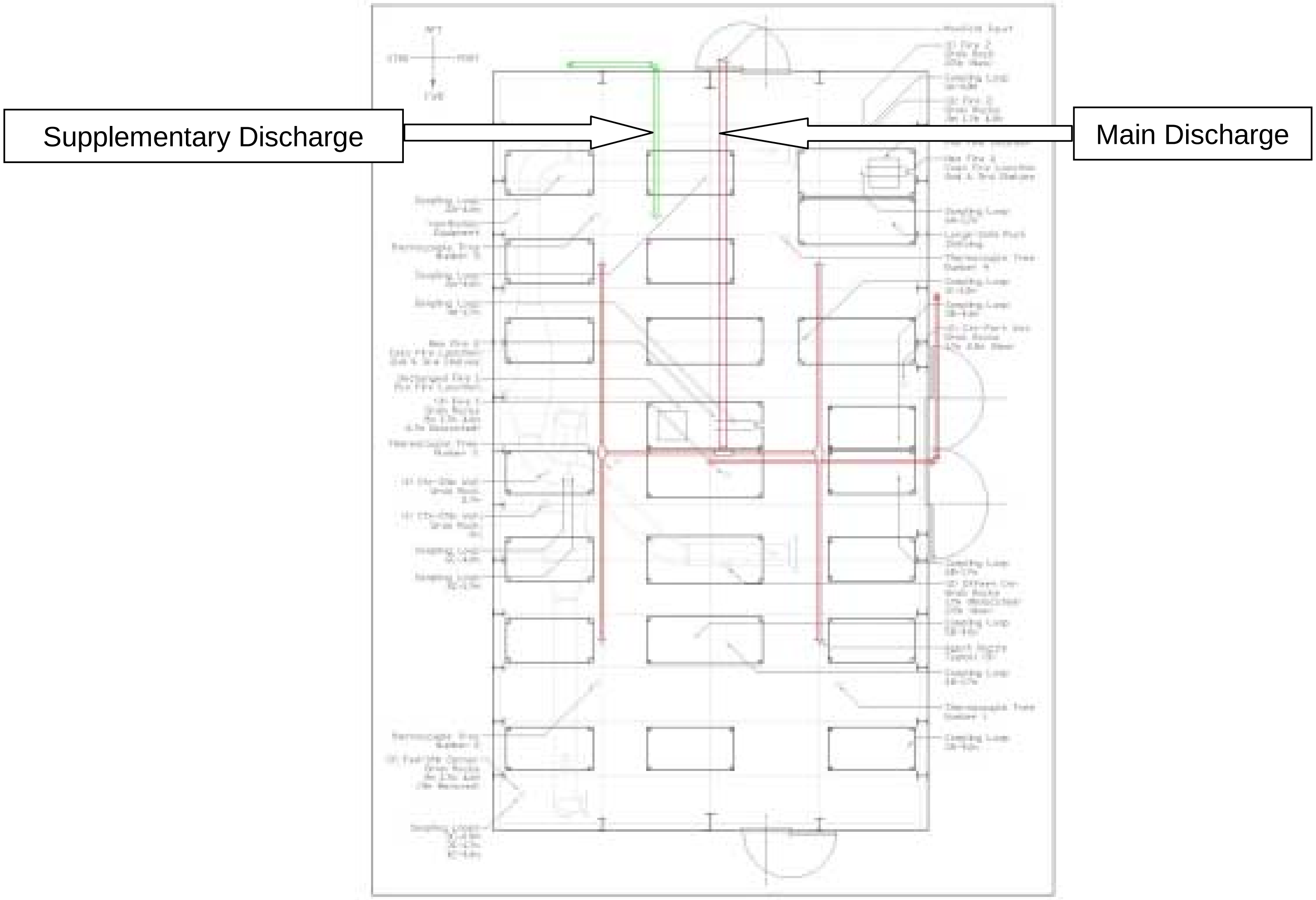
- Three-dimensional
- Introduced on middle shelf
- 330 kW or 1830 kW

Corner Fire Location

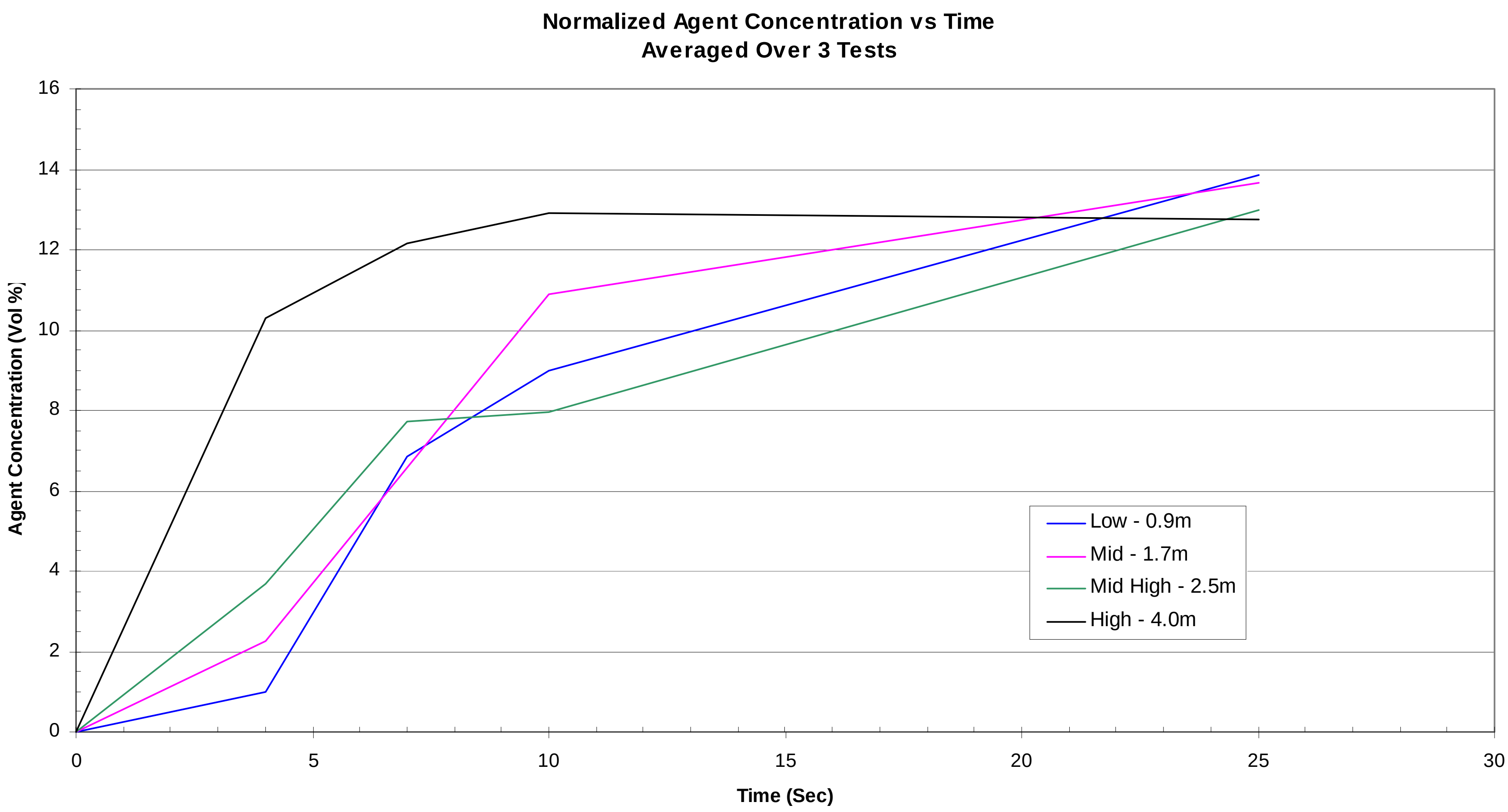
- Challenging fire location – sheltered and mid-height
- The cascading fire fuel is introduced in the second shelf level
- The pan fire is located away from the aisle to realistically limit agent entrainment



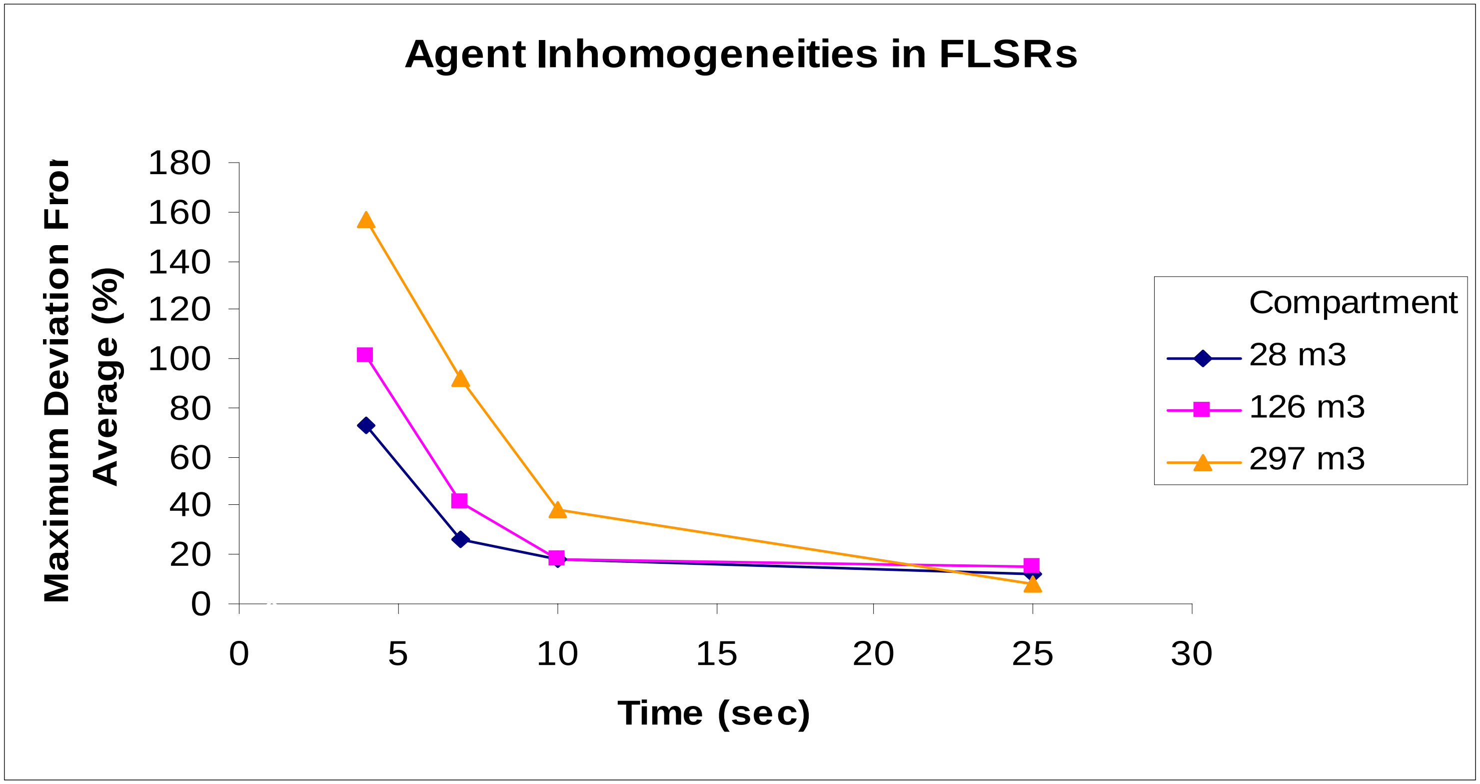
297 m^3 Compartment Layout



Vertical Distribution of HFC-227ea Concentrations



Agent Inhomogeneities



- More deviation in larger compartments
  - Areas of significantly lower concentrations
- Increased vulnerability at low concentration areas

Inhomogeneities

- Significant increased inhomogeneity due to increased ceiling height
  - Standard Navy nozzles discharge horizontally only in order to avoid injuring personnel
- Ceiling height and compartment volume affect adequacy of suppression
  - Produce areas of high and low concentrations
- Must ensure sufficient concentrations of agent throughout space to be protected

Remaining Technical Issues

- Achieving sufficient agent concentration in high obstructed spaces
- Enabling rapid post-fire reclamation of compartment
  - Heat, high HF concentration

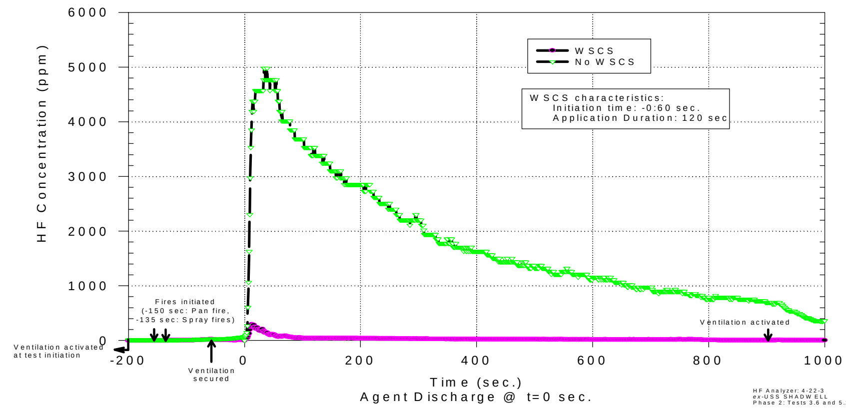
Research Directions

- Current
  - Evaluate effectiveness of
    - Additional nozzles at 2.7 m height
    - Increase in HFC-227ea concentration to 13%
- Future
  - Water Spray Cooling System (WSCS) for flammable liquid store rooms

Water Spray Cooling System (WSCS)

Simple, low pressure water system developed to be used together with gaseous agent systems to address their deficiencies

- Minimizes HF
- Provides cooling
- Minimizes re-flash
- Facilitates re-entry



US Patent 5,918,680, July 9, 1999

Observations

- Full scale testing relevant to the application is needed for validation
- Compartment volume, height, and obstructions increases produce greater agent inhomogeneities
- Low concentration areas can cause unacceptably long fire extinguishment times and high HF concentrations
- Increased design concentrations are likely needed to combat areas of low concentration
- Water Spray Cooling System addresses high HF concentrations and lack of cooling of gaseous suppressants

Shipboard Systems

- NRL design guidance used for HFC-227ea systems aboard the LPD-17 and CVN-76, two new US Navy ship classes
- NRL patented WSCS hybrid system used to replace Halon 1301 systems aboard 60 US Army watercraft in engine room spaces up to 1700 m^3